ABSTRACT – NOT FOR PUBLICATION

Lunar Reconnaissance Orbiter (LRO) Guidance, Navigation and Control (GN&C) Overview

Joseph Garrick
James Simpson
Neerav Shah

The National Aeronautics and Space Administration's (NASA) Lunar Reconnaissance Orbiter (LRO) launched on June 18, 2009 from the Cape Canaveral Air Force Station aboard an Atlas V launch vehicle and into a direct insertion trajectory to the Moon. LRO, which was designed, built, and operated by the NASA Goddard Space Flight Center in Greenbelt, MD, is gathering crucial data on the lunar environment that will help astronauts prepare for long-duration lunar expeditions. The mission has a nominal life of 1 year as its seven instruments find safe landing sites, locate potential resources, characterize the radiation environment, and test new technology. To date, LRO has been operating well within the bounds of its requirements and has been collecting excellent science data – images taken from the LRO Camera Narrow Angle Camera of the Apollo landing sites appeared on cable news networks. A significant amount of information on LRO's science instruments is provided at the LRO mission webpage.

LRO's Guidance, Navigation and Control (GN&C) subsystem is made up of an onboard attitude control system (ACS) and a hardware suite of sensors and actuators. The LRO onboard ACS is a collection of algorithms based on high level and derived requirements, and reflect the science and operational events throughout the mission lifetime. The primary control mode is the Observing mode, which maintains the lunar pointing orientation and any offset pointing from this baseline. It is within this mode that all science instrument calibrations, slews and science data is collected. Because of a high accuracy requirement for knowledge and pointing, the Observing mode makes use of star tracker (ST) measurement data to determine an instantaneous attitude pointing. But even the star trackers alone do not meet the tight requirements, so a six-state Kalman Filter is employed to improve the noisy measurement data. The Observing mode obtains its rate information from an inertial reference unit (IRU) and in the event of an IRU failure, the rate data is be derived from the star tracker, but with degraded pointing performance. The Delta-V control mode responsibility is to maintain attitude pointing during the cruise trajectory, insertion burns and lunar orbit maintenance by adjustments made to the spacecraft's velocity magnitude and vector direction. The ACS also provides for a thruster based system momentum management algorithm (known as Delta-H) to maintain the system and wheel momentum to within acceptable levels.

In the event an anomaly causes the LRO spacecraft to lose the ability to maintain its current attitude pointing, a Sun Safe mode is included in the ACS for the purpose of providing a known power and thermally safe coarse inertial sun attitude for an indefinite period of time, within the manageable limits of the reaction wheels. The Sun Safe mode is also the initial spacecraft control mode off of the launch vehicle and provides for a means to null tip-off rates immediately after separation. The nominal configuration is to use the IRU for rate information in the controller. In the event of a gyro failure a gyroless control mode was developed that computes rate information from the CSS data.

In addition to a detailed description of the onboard ACS, the hardware suite is described. The most basic sensors used on LRO to determine spacecraft attitude are 10 Adcole Coarse Sun Sensors. These small devices collect sunlight, which is then processed by the onboard flight software and converted into a three dimensional estimate of where the Sun is relative to the spacecraft body frame. Fine pointing attitude determination is accomplished by two SELEX Galileo Star Trackers (ST). These STs have a 16° x 16° field of view and produce a quaternion attitude solution in the ST frame with respect the J2000 Earth Centered Inertial reference frame. Each tracker produces an attitude solution at 10 Hz, but for the LRO application is read and processed at the ACS cycle of 5 Hz. The Honeywell MIMU serves as a single IRU, which contains 3 ring laser gyros (one gyro per axis) used to produce spacecraft inertial body rates; there are no accelerometers in the LRO application. This unit outputs an accumulated angle which is sampled by the onboard system at 10 Hz and differenced to produce the body rates. These 10 Hz rate estimates are averaged over two samples to provide a rate for use in the feedback loop at the ACS cycle time of 5 Hz. Fine pointing control of the LRO spacecraft is accomplished through the use of four reaction wheels (RW). These actuators were developed, built, tested, and delivered for spacecraft integration in-house by the NASA Goddard Components and Hardware Systems Branch. The RWs are mounted in a pyramid orientation with combined reaction wheel assembly system momentum storage capacity at approximately 130 Nms. The Propulsion Deployment Electronics (PDE) has a number of functions used to complete the LRO mission. The PDE commands the firing of the thrusters when desired as well as firing of the NASA Standard Initiators for opening of the propulsion pressurization tank and turning on and opening the Non Explosive Actuators for Solar Array and High Gain Antenna deployments.

Immediately after separation, the default control mode, SunSafe, must remove the tip-off rates and place the spacecraft in a power-positive orientation autonomously. Afterwards, the deployables are extended to put the spacecraft in its flight configuration. The GN&C hardware as well as other subsystems are powered on and the ACS mode is transitioned to Observing mode. Thruster one-shots are performed to ensure thrusters are in working order, and the communication is switched from omni-directional antenna to the high gain antenna. One day after launch, LRO conducted a mid course correction maneuver to adjust the inclination of its orbit. After the mid course correction, LRO cruised towards the moon with little excitement for three days. On the fifth day after launch, June 23, 2009 at 6:26:26am EDT, LRO completed a flawless Lunar Orbit Insertion (LOI) maneuver to place itself in an elliptical orbit about the Moon. Over the next five days, four more LOI maneuvers transferred LRO into its commissioning orbit. Over the next ten weeks, the spacecraft and instrument teams commissioned their respective systems. Commissioning is when the GN&C Team had a chance to test out its primary attitude control mode as well as calibrate all of its systems. Once commissioning was completed, a series of thruster maneuvers, mission orbit insertion, lowered LRO into its nominal 50 km mean mission orbit, where it has begun collecting meaningful science data.